"On the Production of Vibrations and Sounds by Electrolysis."

By George Gore, Esq. Communicated by Professor Tyndall. Received November 12, 1861. Read December 12, 1861*.

1. Under some circumstances, which I have already briefly recorded (Proceedings of the Royal Society, No. 44. p. 177), vibrations of singular beauty, accompanied by definite sounds, are produced at the surfaces of mutual contact of a liquid metal and electrolyte by the passage of an electric current.

2. The most convenient mode of obtaining the vibrations and sounds is as follows. Take a circular disk of thin sheet glass about 2 or 3 inches in diameter, and procure a thin hoop of glass about 1 inch wide and of the same diameter as the disk, by cutting off the end of an ordinary glass shade. Coat one edge of the hoop with melted sealing-wax, and place the hoop with that edge downwards upon the disk in an oven so that the two may become securely united. Procure another hoop about $\frac{1}{4}$th of an inch wide, and of a diameter about $\frac{1}{4}$th of an inch less than the previous one, and fix it to the same side of the disk concentric to the other in a similar manner, and make the junctions water-tight. A circular vessel surrounded by an annular space or vessel will thus be obtained, as represented in the annexed figure 1, which gives a perspective view of the complete vessel supposed to be cut in two.

Fig. 1.

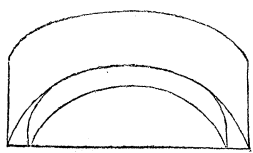
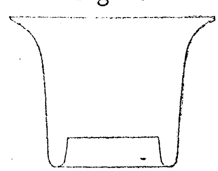


Fig. 2.



A second form of vessel may be made of the shape represented in fig. 2, open at each end; and a bottom formed to it by sticking on with sealing-wax, either a flat disk of glass or an inverted watch-glass. An equally suitable vessel may be made in one piece of glass by forming what is termed by glass-blowers a "chevril" or raised edge in the bottom of a cup (see figs. 3 and 4); or by sticking a

* An abstract of this Paper has already appeared in the 'Proceedings,' vol. xi. p. 491. It is now printed in full by order of the Council.

thin globe of glass upon the form of fig. 2 while in a molten state, and cutting off the superfluous portion when cold (see fig. 5).

The most useful form of vessel is that of fig. 5. In some cases I have employed vessels similar to that of fig. 1, with a *series* of

Fig. 3.

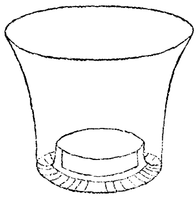


Fig. 4.

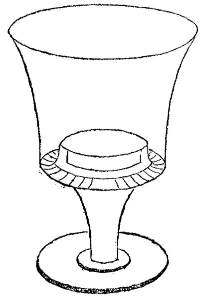
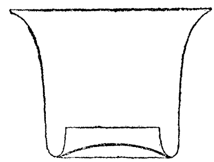


Fig. 5.



annular spaces within each other, to as many as twelve, and to a size of $8\frac{1}{2}$ inches diameter*.

3. Nearly fill the inner circular space and the annular groove with pure mercury, and cover the mercury to about half an inch or more in depth with a filtered solution composed either of 10 grains of cyanide of mercury and 100 grains of hydrate of potash dissolved in $2\frac{3}{4}$ ounces by measure of hydrocyanic acid containing 5 per cent. of anhydrous acid; or of 10 grains of cyanide of mercury dissolved in a mixture of 3 ounces of hydrocyanic acid and $\frac{1}{4}$th of an ounce of strong aqueous ammonia: the latter solution must be used directly after it is made, because it soon decomposes and loses its vibrating power.

4. Take either two or three of Grove's cells, containing platinum plates about 6 inches long and 4 inches wide, connect them intensity fashion, and immerse the positive terminal platinum wire in the circular pool of mercury, and the negative wire in the annular ring of mercury; or five Smee's cells, the acting surface of each silver plate being equal to 30 square inches, charged with one measure of sulphuric acid and nine of water, will do equally well. The polar wires should be guarded from contact with the electrolyte by small tubes of glass melted upon them, and reaching nearly to their extreme points, to prevent dissolving of the platinum and evolu-

* I beg to acknowledge the assistance I have received from Messrs. Osler, glass manufacturers, and their talented manager, Mr. Percivall, in the construction of these and other glass vessels of novel shapes. The above cups may be also obtained of Messrs. Elliott, Brothers, 30 Strand, London.

tion of hydrogen. It is essential that the electric power be within proper limits, otherwise the phenomena will not occur, and I have therefore found it very convenient to employ a wind-up battery, the plates of which can be instantly immersed to any desired depth in the exciting liquid. The one I have used in nearly all the experiments described in this paper consists of ten Smee's elements, each plate being $7\frac{1}{2}$ inches wide and $11\frac{1}{2}$ inches deep, single zincs and single silvers, and capable of being immersed about 9 inches in the exciting liquid; it is sufficiently large to produce the phenomena in rings of mercury $8\frac{1}{2}$ inches diameter and $\frac{1}{6}$th of an inch wide: with small rings of mercury the plates are immersed only $\frac{3}{4}$ths of an inch deep. It is advisable in all cases to produce the sounds by nearly the minimum of electric power, because they are then generally more uniform and more prolonged. The introduction of a coil of stout copper wire (containing a soft iron core) into the circuit will considerably assist the production of sounds if the cells are few in number.

5. Instantly on passing the electric current, a series of small elevations, which I shall term vibrations or crispations, occur upon the surface of the annular portion of mercury, and impart to it the appearance of a series of transverse ridges, all radiating from the centre of the vessel*; and these elevations or crispations are accompanied by definite sounds very similar to the humming of a large bee, and capable of being heard under favourable circumstances at a distance of upwards of 50 feet. The sounds are evidently produced by the vibrations.

6. These elevations are exceedingly definite and uniform in size; apparently all of them are at exactly the same distance asunder at any given moment if the mercury is undisturbed by other causes; the distance varies under different circumstances from about $\frac{1}{6}$th of an inch to a distance so small as to be scarcely distinguishable by the unassisted eye. The apparent distance asunder of each elevation is probably half the distance of the actual vibrations, because the mercury is raised and depressed with great rapidity at each of those spots: while one spot is in a state of elevation, the next adjoining one is depressed; and while the former spot is depressed, the latter is elevated, and so on alternately with such great rapidity as to pro-

* The appearances and their beauty cannot be satisfactorily represented by sketches.

duce upon the eye at any moment the impression of double the number of elevations that actually exist at that moment. Elevations that appeared to be about $\frac{1}{8}$ th of an inch asunder emitted the note F.

7. The *position* of the elevations in very narrow rings of mercury is generally uniform, *i. e.* in lines radiating toward the centre of the vessel when the mercury is undisturbed; but with rings $\frac{1}{4}$th of an inch wide or upwards the elevations of different portions of the ring frequently fluctuate in their positions; and under much rarer conditions the whole ring of elevations revolves (and sometimes rather quickly) round an imaginary axis in the centre of the vessel, sometimes in one direction and sometimes in the other; but what the conditions are that determine the rotation or its direction I have not investigated further than to ascertain that the vibrations are not influenced by a strong magnet. The surface of the negative or vibrating mercury never exhibited *nodal* points.

8. In addition to the elevations which emit sounds, there are other movements of greater amplitude, *i. e.* undulations about $\frac{1}{4}$th of an inch in length; and also other motions of a more violent kind in negative *pools* of mercury, consisting of upheavals of mercury in large masses at irregular distances from each other, as if large bubbles of gas were beneath (but no gas was observed), especially in a solution composed of $2\frac{3}{4}$ ounces of hydrocyanic acid and 100 grains of hydrate of potash, on first electrolysing it. Both these motions, like the previous ones, occur at the cathode, but neither of them are attended by appreciable sounds. On rare occasions, with the full power of the battery exerted upon the solution given (3), undulations have also been observed in the positive mercury surface, but they emitted no perceptible sounds.

9. I have not given a full description of all the numerous appearances of the various movements, as similar phenomena (though produced by other causes) have been minutely described by Mr. Faraday in the Philosophical Transactions of the Royal Society, 1831; and my remarks will be almost entirely confined to the vibrations that produce sounds, because the other electrolytic movements have already been to a great extent observed and examined by previous investigators.

10. The phenomenon of definite sound is limited to those crispations whose widths lie within certain limits; when the widths between the elevations enlarge beyond $\frac{1}{6}$th of an inch, the sounds cease. Fre-

quently feeble sounds are heard a few seconds before crispations appear, and sometimes also a short time after they disappear, especially in a solution composed of $2\frac{3}{4}$ ounces of hydrocyanic acid, 100 grains of hydrate of potash, and 20 grains of cyanide of mercury. In a weak solution of cyanide of potassium the sounds sometimes cease or become inaudible before the elevations disappear; and in other cyanide solutions I have occasionally observed the sounds and crispations continue a short time after the electric current has been stopped; there is probably, therefore, a liquid metal and electrolyte which together will emit sounds without the aid of a battery, and I have made a few experiments (with Hg alloyed with K) to discover them, but without success. In some cyanide solutions the sounds and crispations cease very suddenly; but in the one I have given (3) they remain nearly uniform about ten or fifteen minutes with a feeble electric current, and then diminish gradually as a film is formed upon the anode. The crispations are more steady with a moderate number of large voltaic elements than with a large number of small elements. On some occasions, especially with many elements of small surface, two sets of crispations, one about half the width of the other, will coexist and succeed each other alternately.

11. In every case the PITCH of the sound varied with the *width* of the crispations; the more base the sound, the greater was the distance between the elevations. The loudness of the sound appeared to depend partly upon the depth of the crispations; but this point I have not determined; if the specific gravity of mercury was less, or that of the solution greater, the crispations would probably be deeper and the sounds louder. Shallow crispations formed upon mercury in a solution of iodide of potassium evolved no perceptible sound, although their width was about $\frac{1}{12}$th of an inch. No loud sounds have been obtained. Rings of mercury $8\frac{1}{2}$ inches diameter gave no louder sounds than rings $2\frac{1}{2}$ inches diameter, although the quantity of electricity circulating was much larger, the plates of the battery referred to (4) being immersed 9 inches deep in the former case and only 1 inch in the latter case. A certain amount of *time* is occupied in the development of the vibrations, and is distinctly observable where the electric current is feeble; the vibrations and sounds being gradually developed as the mechanical resistances opposed by inertia, gravity, cohesion, adhesion, friction, &c. of the liquids are gradually overcome. The vibrations are attended by movements in the *mass* of

the liquids, consisting of currents of the electrolyte which flow from the positive to the negative electrode, and of the mercury which flow in an opposite direction; these I shall leave out of consideration, as they are only *secondary* results.

12. Nearly all the experiments described in this paper were made with the solution of cyanide of potassium and mercury already described (3).

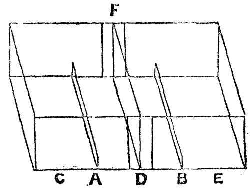
Influence of the Electrodes.

13. The crispations and sounds never (or very rarely, and under conditions which I have not recently met with) occur at the anode; nor had the mass, size, form, or position of surface, distance, chemical composition, or physical condition of the anode any effect upon the direction of the rows of elevations, nor any *direct* effect (their *indirect* effects will be described hereafter) upon the sounds. The elevations and sounds occurred with anodes of all sizes and shapes, and in all positions; also with anodes of platinum wire and sheet. A ring cathode of mercury within a ring anode of mercury gave the sounds equally well. By using a straight and narrow strip of mercury as anode inside a narrow ring cathode, no difference in the size of the crispations at different parts of the ring occurred.

14. With regard to the influence of the cathode, the sounds occurred as well with a very shallow layer of mercury as with a deep mass. Sounds were obtained with nearly as great facility in the central pool (if not too large) by making that the cathode, as in the annular portion. The direction of the rows of elevations was dependent upon the form of the boundary outline of the negative mercury surface; a rectangular surface gave rectangular rows, and a circular surface gave circular rows, and in each case the rows were parallel to the boundary of the mercury surface: a small shallow ring of gutta percha held upon the surface of a large rectangular cathode of mercury caused the rows of crispations to be circular inside the ring, whilst the rows outside remained rectangular. A convenient apparatus, though a temporary one, for examining the direction of the rows of crispations was made by joining together rectangular pieces of thin sheet-glass by sealing-wax in the form shown in fig. 6. The vessel is 3 inches long, 2 inches wide, and 1 inch deep; its lower part is divided into three equal portions by two strips of glass, A and B, about $\frac{1}{4}$th of an inch wide, so as to form spaces C, D, and E for three pools of mercury; a vertical slide of glass, F, rests by its lower edge upon the

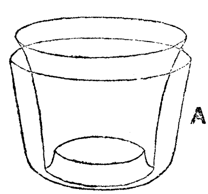
central pool of mercury and separates the supernatant electrolyte into two equal portions, and causes the central portion of mercury to form two connected pools, and to act as a cathode on one side and as an anode on the other, the polar wires being immersed in the outer pools. The sounds and crispations were more definite with narrow strips of mercury $\frac{1}{8}$th of an inch wide than with wider ones, and with annular ones than with circular or rectangular pools: the annular strip may be of any moderate diameter; the best width of mercury to give a definite sound is about $\frac{1}{10}$th of an inch, because there is then only room for two rows of moderate-sized elevations; when the rows are numerous, as in a circular or rectangular pool, the vibrations (and the sounds) are frequently irregular, and interfere with each other. On several occasions fine white sand was sprinkled upon variously shaped negative surfaces of vibrating mercury, but no signs of nodal points were detected. The *liquid* state of the cathode appeared to be essential, as no sounds were produced on substituting a fine stretched platinum wire for the negative mercury. The anode nearly always contracts, and the cathode lengthens during the electrolysis, as may be easily verified by employing *segments* of rings of mercury for the electrodes.

Fig. 6.



15. To ascertain the influence of the chemical nature of the cathode, the glass vessel, fig. 2, open at its lower end, was placed in an outer vessel A, fig. 7, and portions of Dr. Wood's fusible alloy, composed of 1·5 part cadmium, 2 parts tin, 4 parts lead, and 7·5 parts bismuth, were placed in the central cavity and in the annular space; the vessels were then filled about one inch deep, in one experiment with a filtered mixture of 1 ounce of hydrocyanic acid, $\frac{1}{2}$ an ounce of water, and 25 grains of hydrate of potash; and in another experiment with 1 ounce of hydrochloric acid, 1 ounce of water, and 30 grains of chloride of potassium, and the liquid heated by means of a sand-bath to about 180° F. to liquefy the alloy*;

Fig. 7.



* I found by experiment that this alloy solidified at 150°·8 F., and in solidifying

various degrees of battery power were then applied in the usual manner, occasionally reversing the electric current, but no crispations or sounds, nor even undulations, occurred in either case.

Influence of the Electrolyte.

16. The *mass* of the electrolyte is not essential to the sounds, it only increases them by enabling a larger quantity of electricity to circulate; the sounds were readily produced with the thinnest film of liquid upon the surface of the mercury. Several experiments were made to ascertain if the depth of crispations and loudness of sounds would be increased by increasing the specific gravity of the electrolyte by addition of various salts; but no definite effects of that kind were found on gradually adding portions of saturated solutions of carbonate of potash and bromide of potassium to a good phonetic liquid.

17. With regard to the influence of the chemical composition of the electrolyte upon the vibrations and sounds, upwards of one hundred liquids, including organic and inorganic acids, concentrated and dilute—aqueous solutions of caustic alkalies—alkaline carbonates, bicarbonates, borates, hypophosphites, phosphites, phosphates, pyrophosphates, hyposulphites, sulphites, sulphates, bisulphates, iodides, iodates, bromides, bromates, chlorides, chlorates, perchlorates, fluorides, nitrites, nitrates, silicates, tungstates, chromates, bichromates, and manganates—salts of alkaline earths, of alumina, chromium, uranium, manganese, and of various organic acids, all of various degrees of dilution, and with different degrees of battery power, were tried, to ascertain if the property of evolving sounds by electrolysis with mercury electrodes was a general property of electrolytes, or only of certain liquids; but the only ones in which the sounds occurred were moderately dilute aqueous solutions of the cyanides of ammonium, potassium, sodium, barium, strontium, calcium, and magnesium, and best in the cyanides of ammonium and potassium; no sounds occurred in aqueous hydrocyanic acid, nor in a solution of cyanide of mercury. In nearly all the liquids, movements of the mercury, more or less strong, were produced; and in solutions of alkaline hyposulphites, iodides, and bromides, especially the iodides, definite undulations ap-

evolved sufficient heat to raise its own temperature to 155°·3 Fahr. = 4·5 Fahr. degrees. I also previously found that the solution of cyanide of potassium named gave sounds (after a little use) readily at 180° Fahr. with mercury electrodes.

proaching in size and appearance to the crispations were produced, but in no instance did the sounds occur. Solutions of iodide of ammonium and iodide of potassium did not yield sounds with an electric current made intermittent by means of a contact-breaker. In dilute phosphoric acid the anode enlarged, *i. e.* fell more flat, and the cathode contracted*.

18. Numerous experiments were made to determine the most suitable composition of the electrolyte, also to ascertain the effects of deficiency or excess of each of the ingredients. 1st. With regard to the hydrocyanic acid and hydrate of potash, the best proportions were found to be their chemical equivalents (or a slight excess of acid); if either the acid or alkali was in much excess, the latter in particular, films soon formed upon the mercury anode and stopped the action; a very large excess of the acid made the solution liable to become brown and lose its phonetic capacity. 2nd. With regard to the cyanide of mercury, if it was omitted, or if it was present in too small a quantity, the sounds did not occur immediately upon applying the electric current, but only took place after the current had circulated some time (being occasionally reversed in direction), and had thereby caused sufficient cyanide of mercury to be formed; and if it was in excess, the sounds were irregular and feeble. And 3rd. If the solution was diluted with water, the loudness of the sounds diminished, and by further dilution the sounds were altogether prevented; if the solution contained less than 10 or more than 50 grains of cyanide of potassium per ounce, the sounds rarely occurred. An equivalent quantity of strong aqueous ammonia was substituted for the hydrate of potash with equal advantage, except that the solution was much more liable to decompose and become brown; and it is probable that the other alkalies might also be substituted for the potash with success. When a solution becomes brown, it loses its phonetic power; but this decomposition may be prevented, or at least greatly hindered,

* In examining these liquids, I observed that if mercury was shaken strongly in a slightly decomposed mixture of 2 ounces of strong hydrocyanic acid, 1 ounce of water, and 30 grains of calcined magnesia, it remained in a finely-divided state during several weeks, and might be washed many times with water without the globules reuniting; a similar quantity of alumina, or 10 grains of hydrate of potash, was substituted for the magnesia with similar but less effectual results, which, with the potash liquid, were observed only after it was partly decomposed and of a brown colour.

particularly in the cyanide of potassium solution, by not employing too great an excess of hydrocyanic acid, and electrolysing the mixture with mercury electrodes as soon as it is made. From the various results obtained, it is evident that the sounds only occur under very special, limited, and probably complex conditions.

19. The presence of certain impurities in the electrolyte did not prevent the vibrations or sounds; for instance, chloride of ammonium, nitrate of ammonia, or bromide of potassium, added in moderate quantities to the cyanide of potassium solution, produced no conspicuous effect.

20. After the current has been passed a long time in one direction and is then reversed, the crispations and sounds do not occur at the cathode for a little time, partly because a layer of liquid containing an excess of cyanide of mercury has been formed at the surface of that electrode, and a layer of liquid with a deficiency of cyanide of mercury has been formed at the other electrode by the previous electrolytic action; diffusion of these layers by stirring the liquid hastens the reproduction of the crispations and sounds.

21. By repeating the phonetic experiment many times with unguarded wires (4), the cyanide solution gradually loses its power of producing the sounds, probably from acquiring an excess of cyanide of mercury by electrolysis, hydrogen being evolved and mercury replacing it: the loss of power does not result from an alteration in the electrodes, because with the same mercury and a new solution the power was restored, whilst with fresh mercury and the same liquid the power was not restored. The mercury remains unaltered, except absorbing a trace of alkali metal, which is readily removed by washing, and it is therefore not necessary to take fresh mercury for fresh experiments.

Influence of Mechanical circumstances and Temperature.

22. In some solutions (or with a feeble battery), where the crispations did not spontaneously occur, a slight blow with the end of a glass rod against the negative ring induced them to commence, and also a similar blow sometimes stopped them. Frequently, also, when the vibrations have stopped, stirring the liquid reproduces them by mixing the layers of altered liquid that accumulate about the electrodes.

23. Raising the temperature of the solution to about 200° Fahr. appeared to have no *direct* effect upon the vibrations, it only affected them indirectly by allowing more electricity to circulate. The apparatus employed for hot solutions was that shown in fig. 7 (15).

Influence of the Electric Current.

24. In nearly all cases the vibrations and sounds were essentially dependent upon the passage of the electric current, and ceased the instant the current was stopped; the exceptional cases being those already mentioned (10), in which the sounds continued a short time after the current was stopped: it is probable that in those cases local electric currents were produced by the action of the water upon a minute quantity of potassium contained in the mercury, and which had been deposited by the previous electrolysis.

25. With regard to the influence of the *direction* of the electric current; the vibrations and sounds only occurred where the current passed from the electrolyte into the metal, never (or very rarely, and under conditions which I have not recently met with) where it passed from the metal to the solution. No direct effect of the direction of the current in the mass of the electrolyte upon the crispations was detected by passing the current either vertically or horizontally through the solution into the cathode.

Influence of Size and Number of the Voltaic Elements.

26. Twenty Smee's elements, $2\frac{1}{2}$ inches wide, and immersed $\frac{1}{4}$th of an inch deep, with a mercury ring $1\frac{3}{4}$ inch diameter and $\frac{3}{16}$ths of an inch wide, gave crispations $\frac{1}{7}$th of an inch wide, and a coarse base sound; whilst four Smee's elements, $7\frac{1}{2}$ inches wide, and immersed 9 inches deep in the same acid mixture, gave, with the same ring, fine crispations about $\frac{1}{32}$nd of an inch wide, and a high tone; and one Grove's cell, with a platinum plate 12 inches wide and 18 inches deep, and the same ring, gave very faint sounds of high tone without visible crispations in the negative ring, and with fine crispations if the *pool* of mercury formed the cathode. The crispations produced by the twenty small Smee's cells (charged either with acid 1 to 8 or 10 of water or 1 to 24) were less regular than those produced by ten elements of the same surfaces, or five pairs of the larger elements.

27. The least number of Grove's cells, containing platinum plates

6 inches long and 4 inches wide, with which I have been able to produce a *continuous* sound, has been one; and of Smee's cells three (28), except under certain special conditions (36): the most suitable number of the former is two, and of the latter from five to ten, according to their size; if this amount of power was much exceeded, the action became violent, then quiescent, and the sounds ceased.

28. With a ring of mercury $\frac{1}{9}$th of an inch wide and $1\frac{7}{8}$ inch diameter, the *smallest* number of the Smee's cells (4),—1st, immersed $8\frac{1}{2}$ inches, with which the sounds could be obtained was *two*; the pitch of the sound was rather high and very feeble; it lasted only about three seconds, and was not attended by any visible vibrations: 2nd, immersed 5 inches, was *three*; the tone was high and sound feeble, for a few seconds with visible crispations, and continued after that more feeble and without visible vibrations: and 3rd, immersed $\frac{1}{2}$ an inch, was *four*; the sound was steady, tone moderately high, and crispations $\frac{1}{12}$th of an inch wide. And the *largest* number that could be successfully used,—1st, immersed $8\frac{1}{2}$ inches, was *eight*, and occasionally *nine*; the crispations were then very narrow and the action violent: and 2nd, immersed 5 inches, was *ten*, crispations very narrow and action violent. The largest surface of the *ten* Smee's elements that would produce definite crispations and sounds was about $7\frac{1}{2}$ inches deep by $7\frac{1}{2}$ inches wide; and the smallest surface of *three* elements that would effect it was about 1 or 2 inches deep by $7\frac{1}{2}$ inches wide, and then only faint sounds were produced, lasting about two seconds, and unattended by visible vibrations. It is worthy of remark, that a small number of elements of large surface always produced small crispations and high sounds.

Influence of Quantity of the Current.

29. The width of the vibrations and the pitch of the sound are closely connected with, though not solely dependent upon (40), the quantity of electricity which passes into a given amount of mercury surface in a given time. With a surface of given size, the width of the crispations was invariably decreased, and the pitch of the sound raised, by either increasing the number of the plates (their depth of immersion remaining the same) or their depth of immersion. To ascertain the most suitable quantity of electricity, a voltameter was included in the circuit with the phonetic liquid; the negative ring of

mercury was $2\frac{1}{4}$ inches external diameter, and $\frac{1}{10}$th of an inch wide =about 0·675 square inch of surface; the battery consisted of ten Smee's elements $7\frac{1}{2}$ inches wide (4) immersed $1\frac{1}{2}$ inch in the exciting liquid, and the quantity of hydrogen evolved in the meter whilst the ring produced a moderate and steady sound, was 0·47 cubic inch in three minutes; therefore, with the solution of cyanide of potassium given (3), the quantity of electricity required to give a good sound in a ring containing 1 square inch of mercury surface is equal to that which will evolve about 0·232 cubic inch of hydrogen per minute; this quantity approaches the minimum required for the purpose. In a series of four other experiments with a ring of mercury containing just one square inch of surface, and yielding a steady sound, the following quantities of hydrogen were evolved in 3 minutes:—A 0·7, B 0·69, C 0·71, and D 0·685 cubic inch; that is, A 0·233, B 0·230, C 0·236, and D 0·228 cubic inch per minute: average = 0·2317 cubic inch per minute.

30. In all cases an increase in the quantity of electricity passing (either by increase in the depth of immersion of the battery plates, enlargement of the anode, diminution of the cathode, diminution of conduction-resistance in the circuit, removal of films from the anode by stirring, mixture of strata of exhausted electrolyte by stirring, rise of temperature of the electrolyte, &c.) was attended by an increase in the number and a diminution of the width of the crispations, until at length, by excessive quantity of electricity passing, the movements became violent, and the crispations and sounds suddenly ceased. Too large or too small a quantity of electricity produced undulations (8) without sounds.

31. With a given electric current, a wide strip of mercury gave wide crispations and a base sound, and a narrow strip gave narrow crispations and a high sound, because in the latter case the quantity of electricity passing into a given amount of surface was greater than in the former. Diminution of the conductivity of the electrolyte by dilution with water appeared to decrease more the *loudness* of the sounds than to alter their note, probably by decreasing the specific gravity of the solution, and thus diminishing the *depth* of the crispations.

32. In producing the sounds in a circular pool of mercury by gradually immersing the battery plates, the first effects are furrows

in the surface of the negative mercury parallel to the boundaries of its surface, *i. e. circular* furrows, one within the other; on immersing the plates deeper, transverse furrows occur superimposed upon the others, and thus give rise to the little heaps or elevations (5, 6, 7) of mercury; the sounds do not occur until the *latter* furrows are produced.

Similar effects may be produced by *mechanical* means: if a watch-glass containing a little mercury is affixed by means of sealing-wax to a flat and horizontal strip of window-glass about 8 inches long and 3 inches wide, supported firmly at its ends, and vibration be induced in the mercury by resting the end of a vertical glass rod upon the strip of glass, and drawing wet fingers with pinching pressure down the rod, and the vibration be gradually augmented, a similar series of changes will be produced by the gradual increase of mechanical power to those produced by a gradual increase of electric power.

Influence of the Vibrations upon the Electric Current.

33. It was found, by interposing a galvanometer (with a short and thick wire) in the circuit, that when the vibrations ceased, as they sometimes do very suddenly, the quantity of the electricity passing was instantly diminished, the needles shifting from 22 degrees to 18—an effect, no doubt, of exhausted solution accumulating at the electrodes. To ascertain if the vibrations of the mercury and electrolyte made the electric current *intermittent,* the current from three Smee's elements, $7\frac{1}{2}$ inches wide, immersed $8\frac{1}{2}$ inches in the exciting liquid, was allowed to circulate through the primary wire of a Ruhmkorff's induction-coil (kindly lent to me by Professor G. G. Stokes) (the break-hammer being excluded) and the phonetic liquid, the ends of two fine platinum wires from the secondary terminals being in contact with a drop of solution of iodide of potassium, but no signs of decomposition of the iodide could be detected with the aid of an eye-glass; on applying, however, the secondary terminals to my tongue, rather sharp shocks were experienced, and could be very distinctly felt with the damp fingers of my two hands; also a piece of iron of proper size, and suitably held near or in slight contact with the iron core of the coil, could be distinctly felt to vibrate. If only two of the elements, immersed $8\frac{1}{2}$ inches, were employed, and the mercury electrodes reversed for a short time and then returned to

their former position, and thus a temporary suspension of the vibrations (20) was obtained, no shocks were experienced at the secondary terminals until the vibrations spontaneously recommenced—they were then felt distinctly; nor were any shocks felt whilst a platinum cathode of equal surface (one square inch) to the one of mercury was employed as a substitute for the ring, although an equal quantity of electricity appeared to be circulating; nor were any shocks experienced with two Smee's elements whilst the *pool* of mercury formed the cathode, because no vibrations of the mercury then occurred; but on increasing the number of elements to four (immersed the same depths) vibrations commenced, and induction currents occurred and continued, not only whilst the *phonetic* crispations existed, but also whilst only the circular furrows (32), which emit no perceptible sound, were visible. The absence of induced currents with a battery nearly but not quite strong enough to produce vibrations of the mercury, did not arise from a stoppage of the battery current; for by placing a voltameter in the circuit, conduction was found freely, whilst no movements of the mercury could be seen. The strength of the induced currents increased with the loudness of the sounds. It appears, therefore, that the intermittency was not produced by simple electrolysis of the solution, but by the vibrations, and was not limited to such vibrations as produced audible sounds.

Influence of Coils of Wire in the Circuit.

34. Experiment 1. A coil of copper wire containing 154 feet of size "No. 26" was included in the circuit with eight Smee's elements (4) immersed $8\frac{1}{2}$ inches, and a phonetic vessel: without the coil the vibrations were very fine, and the sound acute and loud; but with the coil they were coarse, and the sound base and feeble. Experiment 2. A coil containing 272 feet of "No. 19" copper wire included in the circuit produced similar effects. And, Experiment 3. A ring of soft iron weighing $27\frac{1}{4}$ pounds, outer diameter 12 inches, inner diameter 8 inches, formed of cylindrical metal 2 inches thick, had wound upon it in the manner of an electro-magnet $152\frac{1}{2}$ feet of four parallel and separately-insulated copper wires, size "No. 17." Six pairs of plates, immersed $8\frac{1}{2}$ inches, were connected in circuit, first with one length, and then with two, three, and four continuous lengths of the wire; every additional length of the wire made the vibrations

wider, the sound baser and more feeble. With three elements only and the total length ($610\frac{1}{2}$ feet) of wire in the circuit, the crispations were coarse and the sounds very feeble; and on adding to the length of the wire by interposing an electro-magnet* containing 390 feet of "No. 12" copper wire, the vibrations and sounds were scarcely perceptible. With twenty Smee's elements, $2\frac{1}{2}$ inches wide and $\frac{1}{4}$ inch deep, crispations $\frac{1}{7}$th of an inch wide occurred, and were unaffected by introducing 240 feet of coiled double copper wire (size "No. 17") into the circuit; whilst with four Smee's, $7\frac{1}{2}$ inches wide and 9 inches deep, the crispations were $\frac{1}{32}$nd of an inch wide, and instantly became $\frac{1}{10}$th of an inch wide on introducing the 240 feet of double wire into the circuit; and with a single Grove's cell, platinum plate 18 inches deep and 12 inches wide, a high and very feeble sound occurred (without visible crispations unless the *pool* formed the cathode); but on interposing the 240 feet of double wire, crispations of moderate width at once occurred in the ring, and evolved a loud sound. Other similar experiments yielded similar results. In all cases the greater the length of the wire (and apparently also the smaller its diameter) up to a certain limit, the louder and more steady were the sounds; and beyond that the feebler were the sounds, until at length both vibrations and sounds entirely ceased.

35. It was repeatedly observed that the smallest number of Smee's elements, immersed $8\frac{1}{2}$ inches, with which the sounds could, under ordinary circumstances, be produced, was three; but on interposing the primary wire of a Ruhmkorff's coil in the circuit, or the wire of the electro-magnet (34*), continuous vibrations and sounds were obtained with only two elements; and with the same battery and a mixed gas voltameter† in the circuit, it required seven to produce sounds without the coil, and five with it.

36. To further examine the influence of coils of wire upon the range of battery power which might be employed, I made a number of experiments, which are not necessary to be described in detail, as they are all of a similar character to those just described (34, 35); the results are as follows:—1st. The introduction of a suitable coil of

* The electro-magnet consisted of a horseshoe 14 inches from poles to bend, formed of a cylindrical bar $1\frac{1}{2}$ inch thick.

† The voltameter contained 33 square inches of acting surface of platinum in each electrode, and was filled with a mixture of 1 measure of pure sulphuric acid and $3\frac{1}{2}$ measures of distilled water.

copper wire (*i. e.* 300 or 400 feet of sizes "Nos. 10 to 14"), containing a massive iron core, enlarged the phonetic range of battery power in each direction; it enabled a less number of elements and a less surface of plate to produce continuous sounds, and also enabled a larger surface of the largest number (10) to be used; in the latter case it probably acted in part by diminishing the quantity of electricity. 2nd. An *extreme* length of thick wire (equal to between 900 and 1000 feet of size "No. 12"), coiled upon massive iron, also enabled a less number of elements to produce a continuous sound, but the vibrations were wider and the sounds much more feeble than with a *medium* length. And, 3rd. A *short* length of thick wire (30 feet of size "No. 10") without an iron core, or a long length of thin wire (154 feet of size "No. 26") without an iron core, did not enable a smaller number of elements to produce continuous sounds. With a small number of large elements, and a coil of thick wire to assist in developing the crispations, it was frequently the case that the sounds did not occur for a short time; and in still feebler cases the mercury required the assistance of mechanical disturbance (22) to enable the crispations and sounds to commence. It appears singular that although a coil of wire must make the current more feeble, it should enable a battery to produce the sounds which was already too feeble to produce them.

37. A massive unexcited thermo-electric battery of thirty pairs of bismuth and antimony, interposed in the circuit with four Smee's elements $7\frac{1}{2}$ inches wide and 9 inches deep, had no perceptible effect upon the vibrations. A fine platinum wire 2 inches long, interposed in a circuit with a battery and phonetic vessel, became red-hot, and caused the vibrations to become wider, and the tone of the sound lower than when the wire was excluded, probably by diminishing the quantity of the current. No new effects were observed on using an intermittent current from the primary wire of a small induction-coil instead of the unaltered current direct from the battery.

Influence of Induction Coils and Iron Cores.

38. A current of electricity from three Smee's elements immersed $8\frac{1}{2}$ inches was passed through the primary wire of a Ruhmkorff's coil (without a break-hammer) and a phonetic vessel; on closing the secondary circuit by a drop of solution of iodide of potassium or by

a wire, the crispations became about one-half their previous width and more steady; the sounds also increased in loudness, and their tone rose considerably. On gradually increasing the number of elements from three to ten, and at the same time gradually diminishing their depth of immersion to $\frac{3}{4}$ths of an inch, these effects of the closed secondary circuit gradually and considerably diminished, and ceased altogether when twenty Smee's elements, $2\frac{1}{2}$ inches wide, and immersed about 1 or 2 inches, were employed. If the current from the ten large elements was passed through the fine or secondary wire of the coil, and a very small phonetic cathode of mercury $\frac{1}{2}$ an inch long and $\frac{1}{10}$th of an inch wide, similar effects were obtained on closing the circuit of the inner coil of large wire.

39. On inserting a cylindrical bundle of iron wires, 6 inches long and $1\frac{3}{4}$ inch diameter, in the axis of the coil of Experiment 2 (34), the coil being in circuit with a phonetic vessel, and three Smee's elements, the crispations became a little wider and the sounds a little more base. Also one length, $152\frac{1}{2}$ feet of "No. 17" copper wire, wound upon the massive soft iron ring of Experiment 3 (34), in circuit with seven elements, immersed $8\frac{1}{2}$ inches, and a phonetic liquid, lowered the tone of the sounds much more than a coil of $137\frac{1}{2}$ feet of "No. 19" copper wire containing no iron core. Much more conspicuous effects of the presence of an iron core were obtained as follows:—The coil of Experiment 2 (34) was connected in circuit with two Smee's elements immersed $8\frac{1}{2}$ inches, and a phonetic ring $1\frac{7}{8}$ inch external diameter and $\frac{1}{9}$th of an inch wide; very narrow crispations occurred, which lasted only about ten seconds; but on inserting the cylindrical bundle of wires, the crispations became double their previous width, and the sounds baser and long continued. And in a second experiment with the coil connected as a double wire 136 feet long, without the core the crispations were continuous and rather narrow, and with the core they were much more coarse and the sounds more feeble.

40. But the most decisive effects, both of core and secondary coil, were obtained with a moveable core $8\frac{1}{2}$ inches long and $2\frac{1}{8}$ inches diameter, containing 6 lbs. of size "No. 32" annealed iron wires; a primary coil consisting of 240 feet of double copper wire, size "No. 17," in circuit with four Smee's elements (4) connected as two pairs, and a secondary coil containing 4243 feet of "No. 26"

copper wire. The presence of an iron core in the coil, therefore, has a similar effect to the coil itself, *i. e.* it makes the vibrations wider and the pitch of the sound lower; and in making the crispations wider, up to about $\frac{1}{10}$th of an inch, the sounds also become louder, and beyond that width the sounds become more feeble; and the presence of a closed secondary coil has the reverse effect, it makes the vibrations narrower, and the pitch of the sound higher. These effects of an iron core diminished on increasing the number of elements to ten, and decreasing their depth to $\frac{3}{4}$ths of an inch, and ceased entirely on employing 20 Smee's elements $2\frac{1}{9}$ inches wide, immersed 1 or 2 inches, the same as with the closed secondary (38).

41. The effects of a closed secondary coil and of an iron core upon the vibrations produced by a current from a battery of low intensity being of opposite kinds, if the two are suitably adjusted, they neutralize each other's effects. The moveable secondary coil containing 4243 feet of "No. 26" copper wire was arranged with the iron core and primary coil of the previous experiment (40), and six of the large Smee's elements (4) connected as three: with the core and without the closed secondary coil, the crispations were very wide; with the closed secondary and without the core, they were very narrow; and with the core and closed secondary acting together, they were of medium width, about the same as if neither the core nor the closed secondary were present: the effects were very conspicuous. These opposite effects of an iron core and closed secondary coil upon the phonetic vibrations are analogous to their opposite effects upon the brightness of the spark at the break-hammer of an induction-coil; the iron core increases, and closing the secondary coil decreases that brightness. A cylindrical core of antimony 9 inches long and $2\frac{1}{4}$ inches diameter, employed instead of the iron core, had no perceptible effect upon the vibrations.

42. A pole of a strong electro-magnet (34) was applied to the end of the iron core of the Ruhmkorff's coil whilst the primary wire (without a break-hammer) was in circuit with a phonetic liquid and three Smee's elements (4) immersed $8\frac{1}{2}$ inches: with the secondary coil closed, and small crispations occurring, magnetization of the electro-magnet slightly raised the tone of the sounds if the magnetic poles in contact were dissimilar, and lowered it if they were similar; and with the secondary circuit open and large crispations occurring, the chief

effect of the magnet was at the moment of its demagnetization; it then affected the tone of the sounds momentarily, and the *position* of the crispations strongly, both when the approximated poles were similar and when they were dissimilar, but in the greatest degree when they were similar.

Influence of Electrolytes in the Circuit.

43. No new effects were observed on interposing in the circuit with a phonetic vessel an electrolytic cell containing mercury electrodes and a solution of iodide of potassium or dilute sulphuric acid, they only appeared to influence the vibrations and sounds by diminishing the quantity of the electric current. Several vessels containing phonetic solutions and annular mercury electrodes were placed in one circuit, and sounds readily produced in all of them at the same time.

Influence of Magnetism.

44. Many experiments were made to ascertain if magnetism affected the vibrations; the phonetic liquid, with cathodes of various sizes, was placed in every imaginable position to the electro-magnet (34) strongly excited, in some cases with the armature of the magnet dipping into the electrolyte, but no effect of the magnetism upon the size or direction of the crispations (or in any other way) was detected.

Communications received since the end of the Session.

I. "On the Synthesis of Tribasic Acids." (Preliminary Notice.) By Maxwell Simpson, M.B., F.R.S. Received July 3, 1862.

I have already shown* that the cyanides of the diatomic radicals (at least those which form glycols) yield bibasic acids when treated with potash, which contain four equivalents of carbon more than the radicals from which they are derived. Analogy would lead us to expect that the cyanides of the triatomic radicals would yield with

* Philosophical Transactions for 1861, p. 61.